Thesis/
Reports
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FINAL REPORT FOR JOINT VENTURE AGREEMENT

Final Report for Joint Venture Agreement
Number 03-JV-11221615-094
"Improving Fire Behavior Modeling Using Prescribed Burns In The Southwest"

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A Joint Venture Agreement (JVA) was entered into between the US Forest Service and New Mexico State University (NMSU) on March 6, 2003. This final report summarizes the entire effort, and covers the period, September 1, 2006 through August 31, 2007, since the last interim report.

This research was supported in part by funds provided by the Rocky Mountain Research Station, Forest Service, U.S. Department of Agriculture. The work reported herein was performed by the PI, Ian Leslie. Assistance in his efforts has been given by a number of people in the USFS and by Los Alamos personnel, in particular Carl Edminster of the USFS and Rod Linn of Los Alamos National Laboratory (LANL) have been most helpful.

A. Introduction

The original intent of this JVA was to apply the LANL computer code FIRETEC/HIGRAD to real vegetation and topology, as typified in the extreme southern border region of Arizona and New Mexico. This region of interest is located in the Malpai Borderlands Area and Peloncillo Mountains. In 1997 a prescribed fire, know as the Maverick Burn, consumed approximately 12,000 acres. The Forest Service planned to reburn Maverick and extend the burn north of Geronimo Trail Road. The budget and work plan for this JVA included funds to instrument and monitor this prescribed burn, or another suitable burn (2003 Baker II, and 2006 Cottonwood burn). The data collected form one or more burns were to be compared to model predictions and serve as part of a validation process.

The Baker II burn was carried out just a few months after the start of the project and could not be prepared for. By the time of the Cottonwood burn, it was clear to the PI that field operations of the scale needed to instrument and monitor a landscape size fire were beyond the scope of the JVA. Indeed, such an undertaking may require a major commitment on the part of multiple interested agencies. In addition, FIRETEC/HIGRAD is very computationally demanding and current computer resources could not realistically handle a fire of several hundred acres, let alone several thousand. At the time of this writing, no computer may exist to adequately model a large fire in any reasonable length of time (days to weeks).

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One proposal, which was suggested by Carl Edminster, was to carry out a small burn (several acres to a few tens of acres) on some area that was skipped during the Baker II burn. Often fires will leave islands of unburned vegetation. While this plan was agreed upon, it was never carried out. The PI does not believe that any fault need be assigned. Rather, such an undertaking, including man power and timing demands, was much greater than the USFS personnel and the PI anticipated in the beginning. Even small prescribed burns require extensive time and commitment to carry out safely.

B. Publications

Five interim reports have been prepared and delivered to the Rocky Mountain Research Station. These reports may be referenced for further detail about the work carried out. This report will provide an overview of past work, and efforts since the last interim report delivered in November 2006.

In addition to the reports, a Master's thesis[1] written by Humberto Silva of the Mechanical Engineering Department at New Mexico State University was completed in June 2004. That work focused on methods of computer code validation. In particular, a metric that compared observed burn regions with predicted burn regions was developed and demonstrated. The validation technique is statistical in nature and follows the method developed by Hills and Trucano[2].

A paper was subsequently written based on Humberto Silva's thesis work. The paper was submitted to the *International Journal of Wildland Fire*. Unfortunately, it was not accepted in its then current form. The editor did say that the material was of interest to the wildland fire community and encouraged the author's to rewrite and resubmit. The rewrite is under way at the time of this writing. If accepted, acknowledgement will be made to the USFS, and the Rocky Mountain Research Station specifically.

C. Model Implementation

With the assistance of Rod Linn of LANL, the PI obtained a copy of FIRETEC/HIGRAD. Originally this code was installed on an older parallel computing system at NMSU. The PI was able to familiarize himself with the code and make some small runs. In late Fall of 2004, the PI, as part of an NMSU group, was awarded $240,000 from NSF for the purchase of a 128 processor Beowulf style computer. One of the projects specifically detailed in the proposal was this JVA. As mentioned already, FIRETEC/HIGRAD is computationally demanding. Thus, the new high performance parallel computer was very welcome.

In order to simulate fires in the Malpai Borderlands Area, it was necessary to have both fuel and topology data. Fuels data was obtained with the assistance of students from the Surveying and Biology Departments at NMSU. Topology data was obtained with help from the Geography Department.

A fuels survey site was chosen just north of Geronimo Trail Road, within a few hundred feet of the Arizona – New Mexico border. The survey location was a short walk from the road. The site was selected for its representation of the fuels expected for a reburn of the Maverick fire and points north. Two reference locations were staked out and GPS equipment was used to locate these points. T-posts marking these spots should still be there. The locations based on NAD 83 UTM, Zone 0012 coordinates are:

CP1: 3486729.58748 N 685102.41280 E
CP2: 3486767.13053 N 684996.61758 E

For ease of finding this location on maps without UTM coordinates, the control points are given in degrees north and west.

CP1: 31^{O} 30' 02.19375" N 109^{O} 03' 03.53092" W
CP2: 31^{O} 30' 03.47353" N 109^{O} 03' 07.51393" W

The surveying students estimated the accuracy of these coordinates to be on the order of one foot. A satellite image obtained form Google Earth® showing the survey region is presented in Fig. 1. Some sense of the vegetation size and density can be ascertained. The majority of the vegetation included manzanita, oak, juniper, pine, and bear grass.

Ten survey circles of 32 ft diameter were established using the references points above and a laser range finding system. Within each of these circles the location, size, and type of vegetation was recorded relative to the circle center and magnetic north. Post processing combined all measurements to give a UTM coordinate for each plant. Some of the circles partially overlapped, but there were areas within the 80 x 80 meter simulation area that were not sampled. Based on the sampled data these areas were filled in with representative vegetation. The end result is shown in Fig. 2. Table 1 is the key to the actual vegetation measured.

Table .1 Plant Species for Fig. 1 Key

Key Name	age	gb	jnpr	man	olive
Species	agave polmari	nolina microcarpa	juniperus osteosperma	arctostaphylos pungens	quercus hypoleucoides
Key Name	pin	po	span	star	xx
Species	pinus cembroides	quercus emoryi	dasyliron wheeleri	quercus toumeyi	agave polmari

Both age and xx were later identified as both being agave.

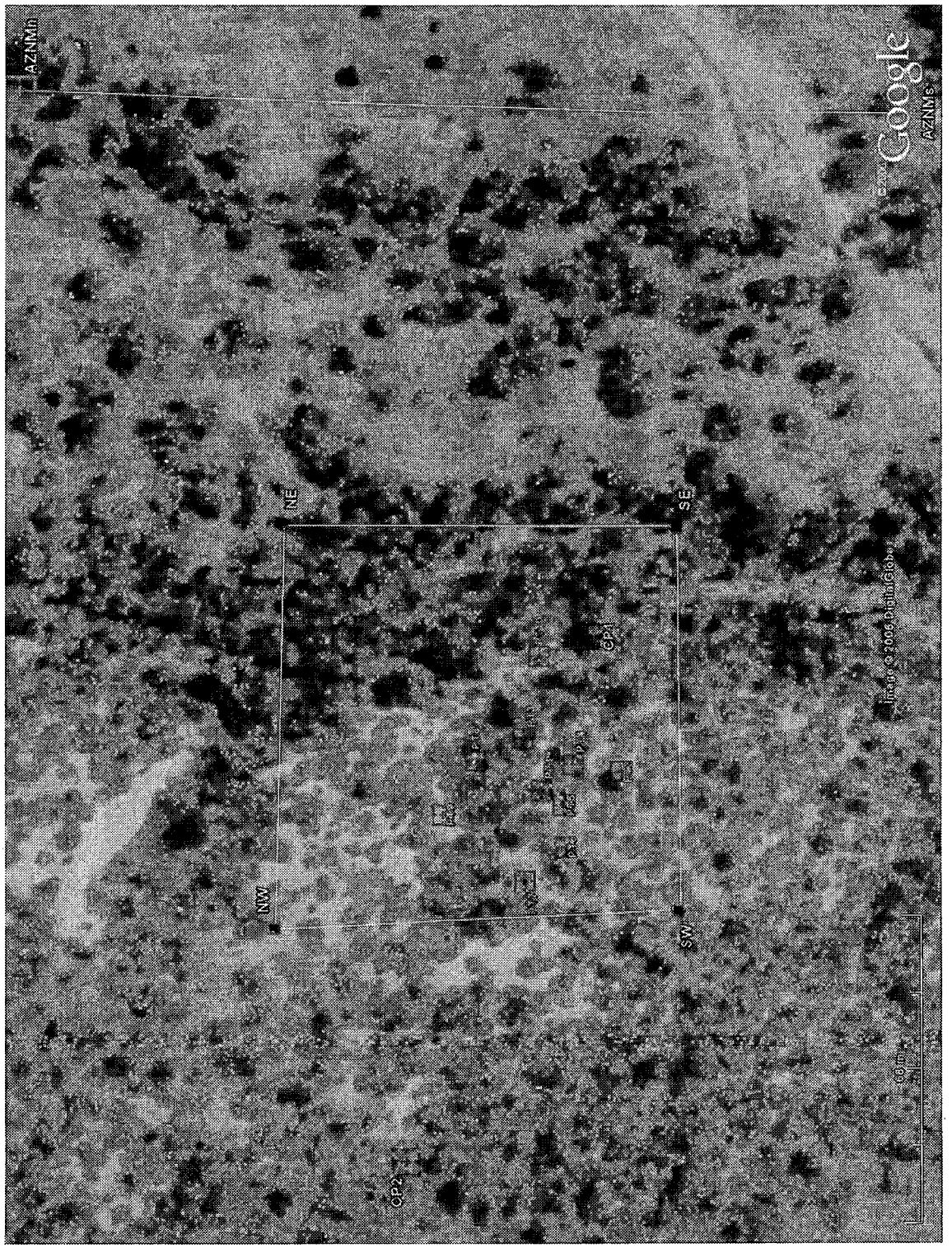

Figure 1. Burn area location and control points using Google Earth®. The rectangle is the simulated burn area. The line at the top (right in landscape orientation) is the Arizona – New Mexico border. Geronimo Trail Road is visible in the upper right.

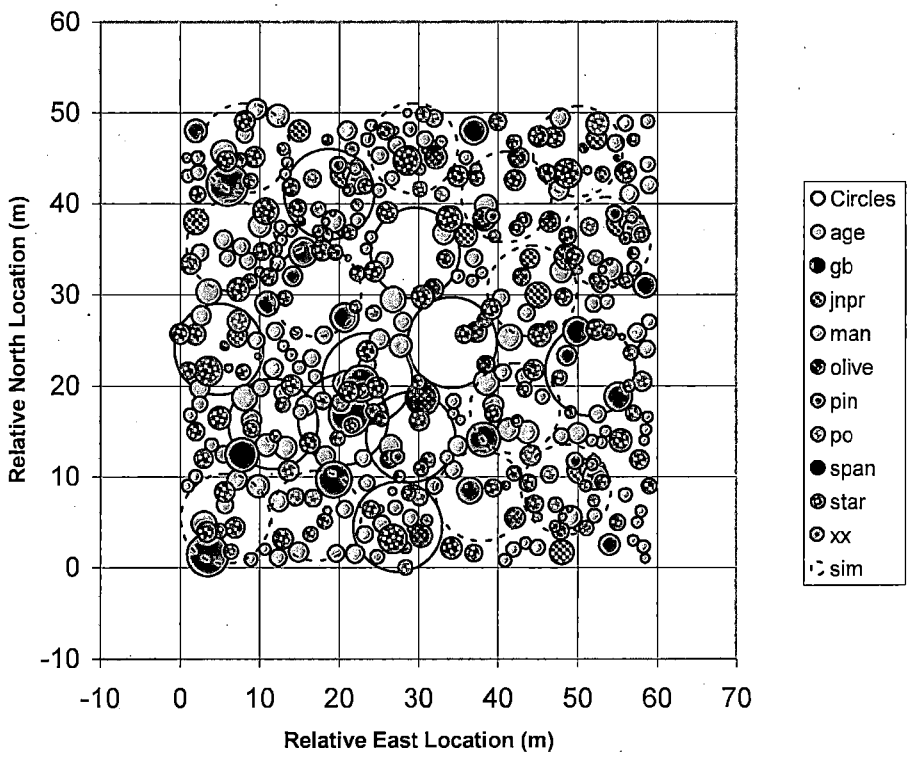

Figure 2. Actual data sampled is within or on solid circles. Simulated data is within or on circles with dashed lines as well as between these circles. The second through eleventh items in the key are plant types (see Table 1.)

Topology data with 10 m horizontal resolution was made available by Janet Greenley of the NMSU Geography Department. These data were obtained from a national data base and sent to the PI in a tabular form. The spatial resolution employed in the fire model was 1m x 1m. This necessitated that the 10 m data be interpolate. A program was written with the programming package Matlab® to accomplish this. A 3-D plot of the topology is shown in Fig. 3. Finally, the fuel size and location data, along with the relative topology data were formatted for input to FIRETEC/HIGRAD. At this point various simulation scenarios were run.

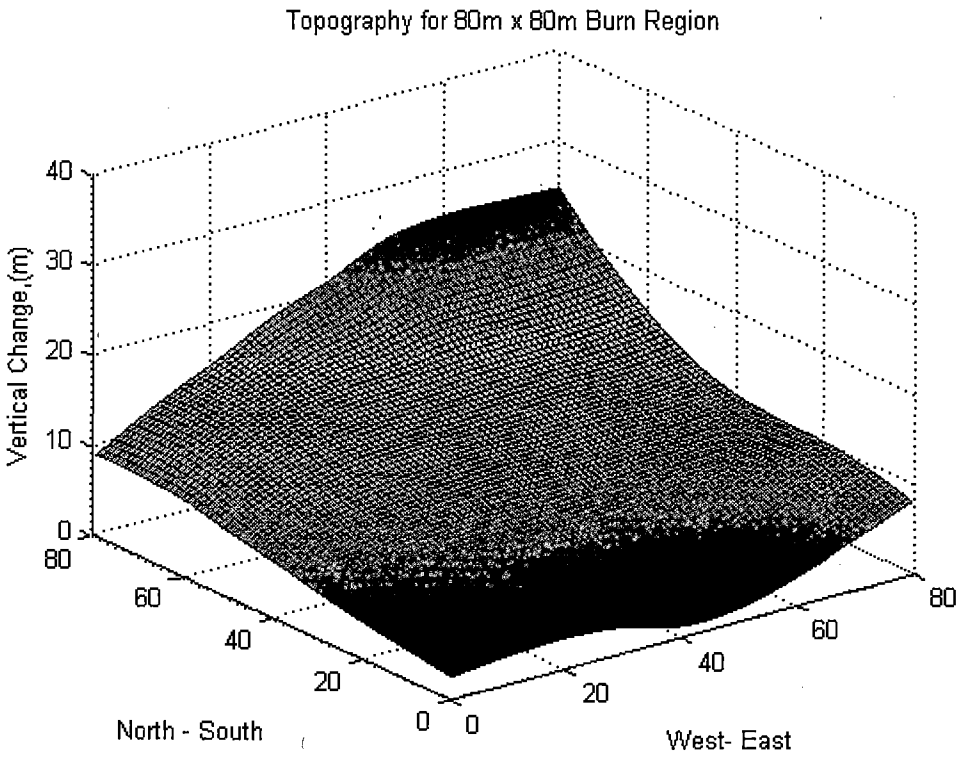

Figure 3. Topography derived from 10 m resolution DEM data using bicubic interpolations. All units are in meters with lowest point set to 1 meter. Vertical scale has been stretched to emphasize elevation changes.

D. Computer Model Runs

Four primary computer simulations were completed. Run conditions are shown in Table 2.

Table 2. Simulation Conditions used with FIRETEC/HIGRAD

Case #	Average Wind Speed	Wind Type	Grass	Litter
1	6 m/s	Constant at inlet	no	no
2	3 m/s	Constant at inlet	no	no
3	3 m/s	Constant at inlet	yes	yes
4	3 m/s	Variable at inlet	Yes	yes

For each case the fuel loading from trees and shrubs was the same. In two cases grass was also included even though little grass was present at the time of the survey in Fall 2004. However, there are times, especially after a season of good rainfall, when significant grass can be present. Grass can be important in carrying a fire, especially in low wind conditions. Due to the way that FIRETEC/HIGRAD was set up, it was convenient to have litter tied to the presence of grass. In

particular, by turning grass and litter on and off together, the extremes in ground cover effect could be assessed.

As any anyone with experience with wildfire can attest to, wind is a major factor in determining the how a fire behaves. With this in mind, both the average magnitude and the variability of the wind were studied for their effect on fire spread. It was discovered that a 6 m/s (13.4 mph) average wind speed, whether steady or variable, carried a fire with or without grass and liter. Thus only the steady 6 m/s results are reported.

Details of the four runs are given in Interim Report #5, but results are given here for the sake of completeness. For each run with a steady wind speed a ramp up time from zero velocity to the final value was set to 6 seconds. This ramp up time was recommended by LANL personnel. The ramp up time is evident in some of the plots that follow as a period of little to no fire spread.

Steady wind at 6 m/s with tree and shrub vegetation only

The plot in Fig. 4 was derived from fire front data extracted from the FIRETEC/HIGRAD output. The front location as a function of time was fitted with a linear function to arrive at an estimate of the rate of spread (ROS). In this case, the ROS is just over 0.3 m/s. It is clear that this is an average and that averages over sorter periods of time could be higher or lower. The flattening after 160 seconds is probably due to the fire approaching the computational boundary. This slowing down is an artifact of the limited domain.

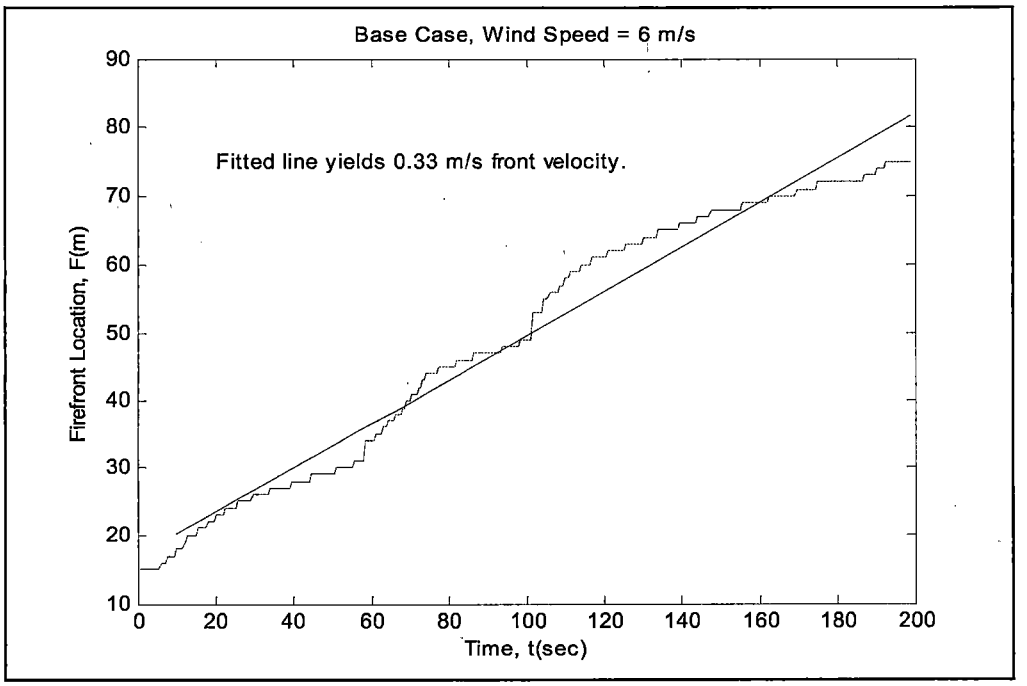

Figure 4. Fire front location versus time for steady 6/m sec wind speed.

Steady wind at 3 m/s with tree and shrub vegetation only

This run was similar to the previous one except for the having a lower wind speed. From Fig. 5 the ramp up time delay is apparent. The sudden acceleration at around 20 seconds may be related to how the fire is started. A long fire line was set all at once. This may result in a sudden flare up because the temperatures are high even before any fuel is burned. Once the fuel starts burning there is a sudden increase in energy output that adds to the original input with a short lived rapid spread. For this reason only the data after this initial transient period was used to estimate an average rate of spread. In this case the ROS is about one-fourth that at the higher wind speed. In this case a reduction in wind speed by one-half has resulted in a four fold decrease in fire spread rate. What is not at all evident from this plot is that it appeared that the fire might be going out. Movies were made of the spreading fires, and it is through watching the movie for this case that it appears that the fire may die out. It is possible that if a significantly longer computer run had been made then the fire may have continued burning. However, this would have depended on the exact location of the vegetation. Any significant gap between a burning shrub and its nearest neighbor in the windward direction might be enough to cause the fire to go out. Thus, the exact details are relevant and one must begin to think in terms of probabilities of continued spread. Unlike the 6 m/s case the fire had not reached the computational boundary.

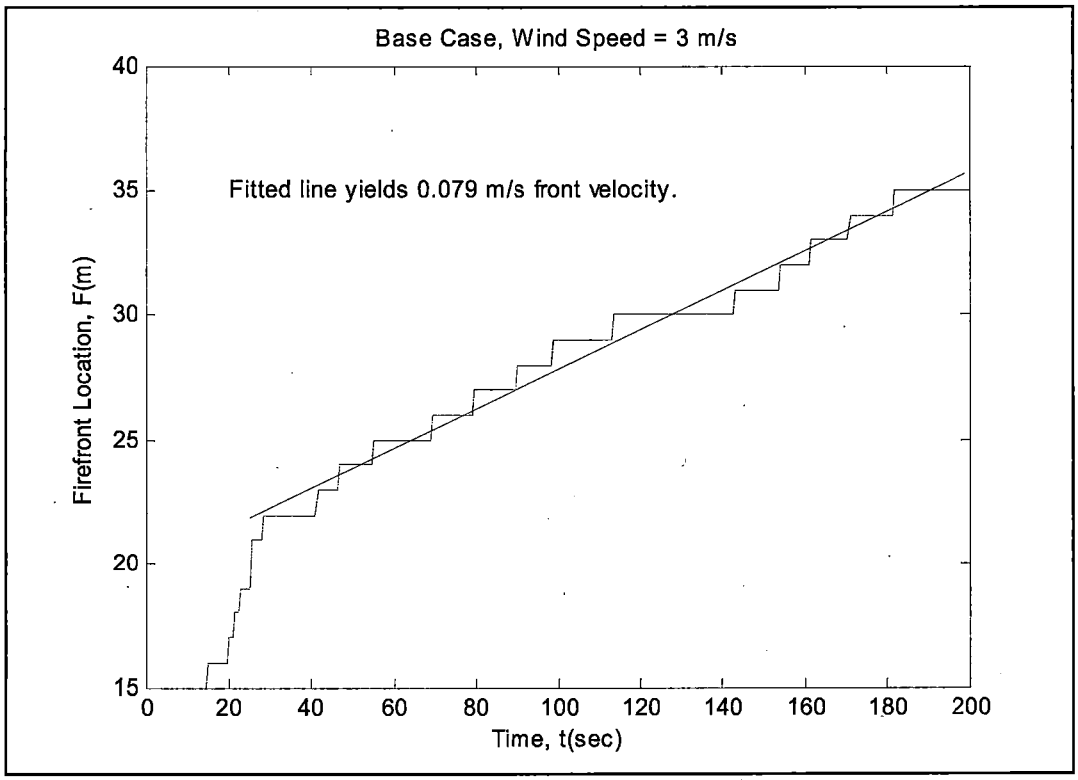

Figure 5. Fire front location versus time for steady 3/m sec wind speed. The step like movement results from periodic sampling of the computational data.

Steady wind at 3 m/s with grass and litter.

The steady wind speed of 3 m/s was repeated with grass and litter added. The values used are shown below and are the defaults used in FIRETEC/HIGRAD.

Litter depth = 0.013 m, litter density = 55 kg/m^3
Grass height = 0.3 m, grass density = 0.54 kg/m^3

As can be seen in Fig. 6, there is a significant increase in rate of spread of about 50%. From the movie there is no evidence of the fire going out, as would be expected if a good grass layer is present.

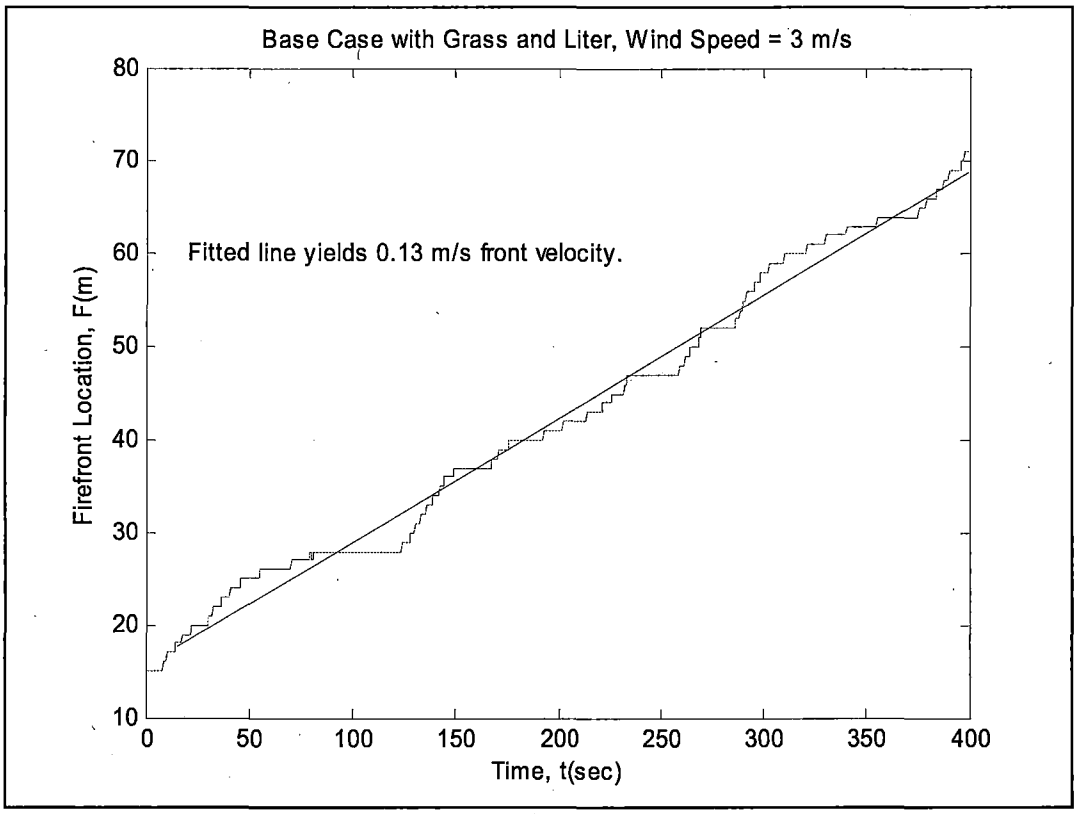

Figure 6. Fire front location versus time for steady 3/m sec wind speed with grass and litter.

Unsteady wind speed with grass and litter.

The last case considered variable wind speed. No specific data was available so a synthetic profile was developed using the following formula.

$$Ws(m/s) = 3 + B_1 \sin(\omega_1 t) + B_2 \sin(\omega_2 t) + B_3 \sin(\omega_3 t)$$

The choices for the B_i and ω_i were arbitrary but were intended to avoid simple repetition over the burn period. The values are given in Table 3, and the profile is shown in Fig. 7. Inspection shows maximum excursions from the 3 m/s mean wind speed of about ± 1.4 m/s.

Table 3. Parameters used for synthetic wind speed formula.

i	B_i	ω_i
1	0.8	$\pi/45$
2	0.5	$\pi\sqrt{2}/45$
3	0.2	$\pi\sqrt{5}/45$

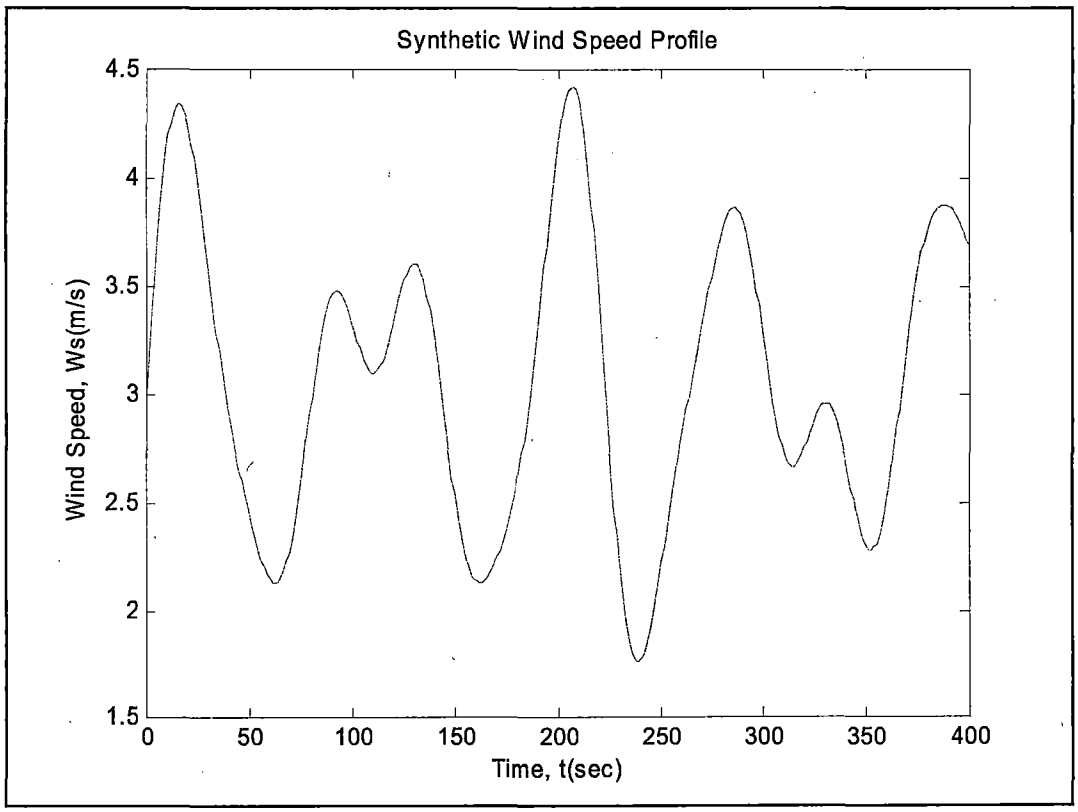

Figure 7. Variable wind speed profile. Average value is 3 m/s.

The fire front location as a function of time is shown in Fig. 8. The mean ROS, taken after the initial startup phase, is only slightly below that for the steady wind speed case, 0.12 m/s versus 0.13 m/s. This is less than a 10% change. However, inspection of Fig. 8 does show more local variability with periods of high and low ROS. Although not exact, there is correlation between the wind speed plot and the local ROS, with high wind speeds resulting in higher ROS. It should be pointed out that output beyond 300 seconds was lost for reasons that are unclear. The actual run went to 422 seconds physical time.

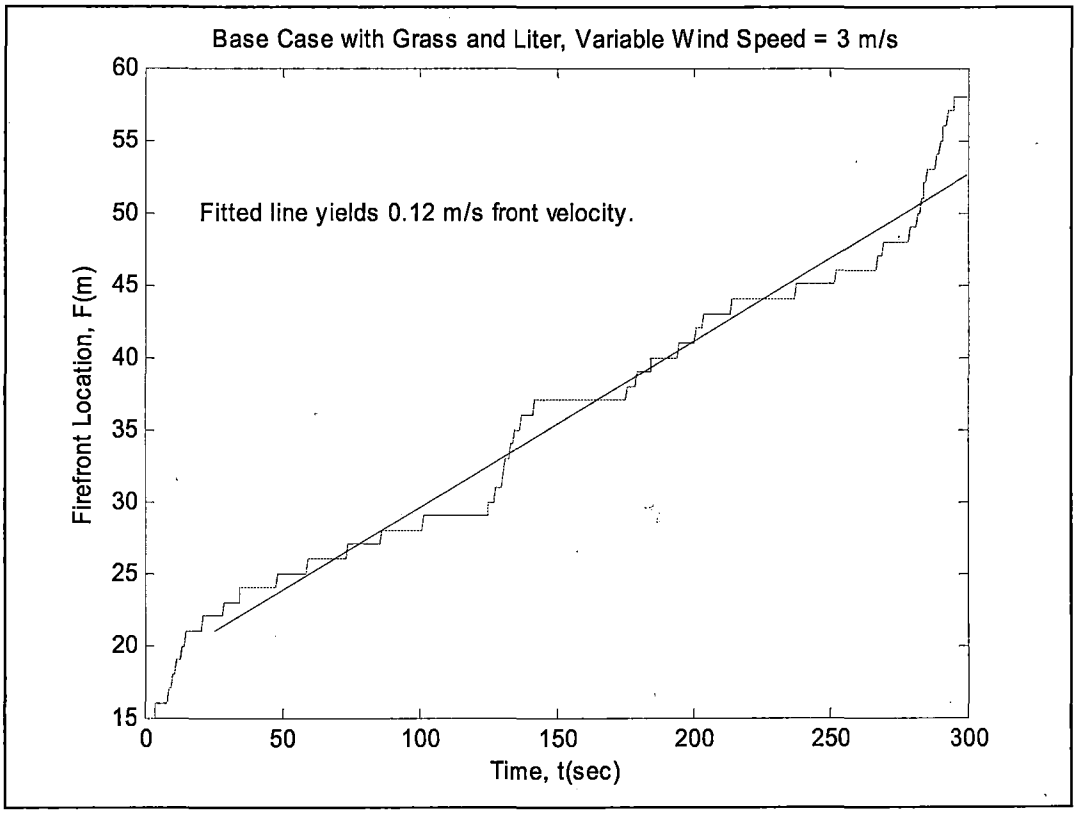

Figure 8. Fire front location versus time for variable wind speed (see Fig. 6).

Summary

Four scenarios were investigated that considered different wind speeds and fuel loading. The case with the lowest wind speed of 3 m/s, and no supplemental fuel in the form of grass and litter, appears to be heading for extinction. This was not the case with 6 m/s wind speed where the fire moved steadily and rapidly to the edge of the computational boundary whether grass or liter was present or not.

The two cases with grass and liter at low wind speed showed that the fire would carry without any indication of it going out. The variable wind speed case did not show any significant difference from the steady wind speed case.

The results obtained are consistent with what would be observed in the field for an actual fire. High winds can drive a fire from shrub to shrub, while grass and/or liter are instrumental in carrying a fire over open ground in the absence of high wind speeds.

E. Conclusions

FIRETEC/HIGRAD can be used as a tool to investigate the relative importance and effect of fuel loading, wind speed, and topography on fire spread. Fuel data is expensive to obtain in detail and methods should be investigated that reduce the labor involved. It is probably not necessary to know the exact location of each plant. A statistical representation of the vegetation, including type, size, and spatial distribution could be used in place of detailed surveying. Such a statistical representation would have to be based on field surveys along with aerial and/or satellite imagery. Validation of such approximate methods would have to be carried out by comparing computer runs to assess sensitivity.

Topological data already exists and can be taken from digital data bases. Thus, no particular efforts need to be taken except for downsizing the 10 m meter resolution data to the smaller grid size used in FIRETEC/HIGRAD.

The computational times are long even on large multiprocessor machines. For regions of tens of hectares, times of the order of a day or more can be expected. At this time FIRETEC/HIGRAD is not for operational use in helping with real time fire fighting. Rather it is a tool to better understand fire behavior, and possible strategies to reduce future fire danger.

As with any mathematically based computer model, validation is important. The best validation method is to compare to the best field data whenever possible. In the case of a wildfire modeling data both before and during the controlled fire would be needed. This was part of the original plan of this JVA. As stated in the beginning of this report, this was never done. It turned out that the level of planning and expense were much too great. The author believes that it can be done, but that a significant effort, possibly among several agencies, will be required.

It is first necessary to know well in advance where the controlled burn will be. This gives the modeler time to get fuel data, at least for the permanent vegetation. Closer to the time of the burn, a survey of grass cover would be required.

In anticipation of the fire, weather monitoring must be planned for. Here weather includes wind speed and direction, humidity, and insolation. This will be quite challenging. Only isolated measurements will be obtained, so some form of interpolation will be necessary. The interpolation can probably be done with an atmospheric weather code, perhaps HIGRAD itself. These data will have to be taken in real time throughout the burn period that is being simulated.

The final challenge will be to document the progression of the fire itself. There are several possibilities, none of which exclude the other. Personnel on the ground could estimate fire line locations using GPS and synchronized clocks (perhaps built into the GPS). In addition, electronic tripping device could be designed to record when a fire line has reached a certain location. This would require that fire direction could be roughly anticipated ahead of time. Such devices could be equipped with low power transmitters. When the fire line came near and temperature reached a preset value, the device would send out a signal with an identifier. In general, the fire would destroy the device but the required data would have already been obtained.

In addition to these ground techniques, aerial photography and/or satellite imagery could be used. For smaller fires aerial photography would probably be best. Both methods would add significant expense.

If and when a controlled burn with validation is considered appropriate, it must be done adequately with detailed planning. The point is to determine if a fire model and its computer based implementation is 'accurate' in some sense that also must be agreed upon. It would be very disappointing if, at the end of the day, no statement could be made about model validity because insufficient data were available form the controlled burn.

It is suggested that all stake holders agree ahead of time what needs to be measured. More than one model exists, and development is on going. Once the data needed to run the codes is obtained, the data would be released. The 'competitors' would run their codes and submit their results to an independent third party in order to assess how well each model performed by comparing predications to field measurements. Results should then be published.

F. Acknowledgements

Carl Edminster of the US Forest Service has been most supportive of this work and patient with the reports. Rod Linn and Judy Wintercamp of Los Alamos National Laboratory have been generous with their help. Thanks to Janet Greenley of NMSU for providing topographic data. Special thanks go to Jesse Canfield of NMSU and LANL for all his help in showing me how to use AVS to produce images necessary and make the fire movies.

References

[1] Silva, Humberto S., Validation Metric for Wildfire Modeling, New Mexico State University Master's Thesis, June 2004, Las Cruces, New Mexico.

[2] Hills RG, Trucano TG. (1999) Statistical Validation of Engineering and Scientific Models: Background, SAND99-1256, Sandia National Laboratories, Albuquerque, NM.